

P 4.12 MESOSCALE MODELING OF THE WINTERTIME BOUNDARY LAYER STRUCTURE OVER THE ARCTIC PACK ICE

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OBJECTIVES

Assess the requirements for obtaining accurate simulations of the Arctic boundary layer and surface fluxes using a 3D mesoscale model.

METHODOLOGY

Critically validate simulations with the Penn State/NCAR Mesoscale Model (MM5) using data from the Surface Heat Flux of the Arctic Ocean (SHEBA) year and modify the model configuration as necessary. Perform simulations for conditions typical of each season. This is the wintertime case.

OBSERVATIONAL DATA & CASE

- measurements at SHEBA site on pack ice in Beaufort Sea (Fig. 1) include 20-m 5-level flux tower, broadband 4-component radiation sensors, cloud radar and lidar, soundings, sodar

-case of Jan. 15-20 (JD 380-385), 1998: no solar radiation, westward moving high pressure north of site (Fig.1), surface temperature -30 - -40°C

-skies generally clear except near 22 UTC Jan 14 - 01 UTC Jan 15, 11-15 UTC Jan 16, 00-11 UTC Jan 18, and after 05 UTC Jan 20 (Figs. 2b & 3). Only the first and last periods had clouds with sufficient liquid water to impact the surface downwelling longwave radiation (Fig. 8a)

- stable Arctic boundary layer (Arctic inversion) top near 900-1600 m (Fig. 2a); planetary boundary layer top, marked by enhanced stability, near 70-170 m (Figs. 2a & 4)

- stability regime analysis indicates that local scaling of Monin-Obhukov Similarity Theory (MOST) is appropriate for most of this time period (Fig. 5)

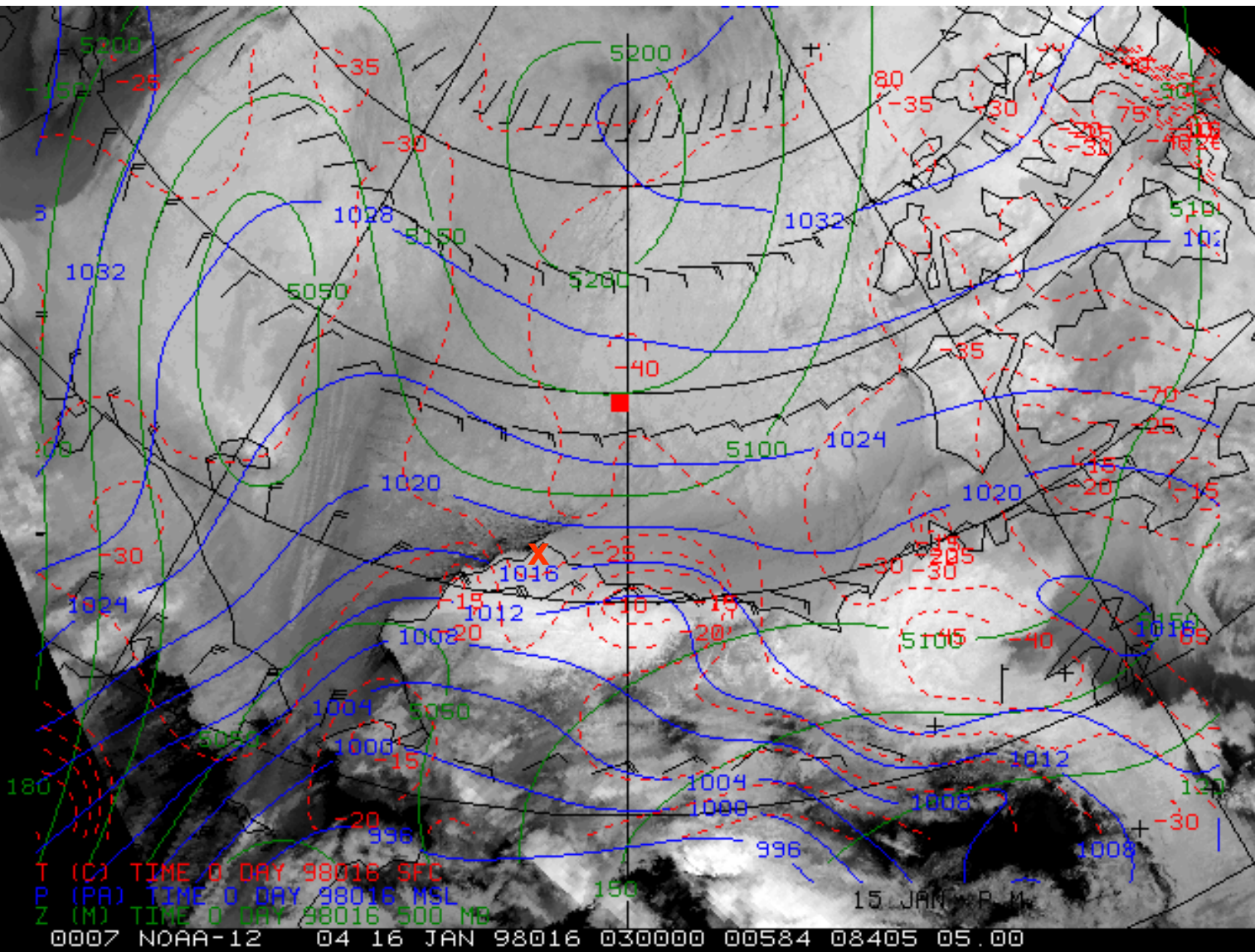


Fig. 1: NCEP analysis of sea-level pressure (mb; blue solid), 500 mb height (m, green solid), surface temperature (deg C; red dashed) and surface wind barbs at 00 UTC Jan. 16, 1998. The IR satellite image from 03 UTC Jan. 16 is overlaid. The red square marks the location of SHEBA ship and the red "x" marks Barrow, Alaska.

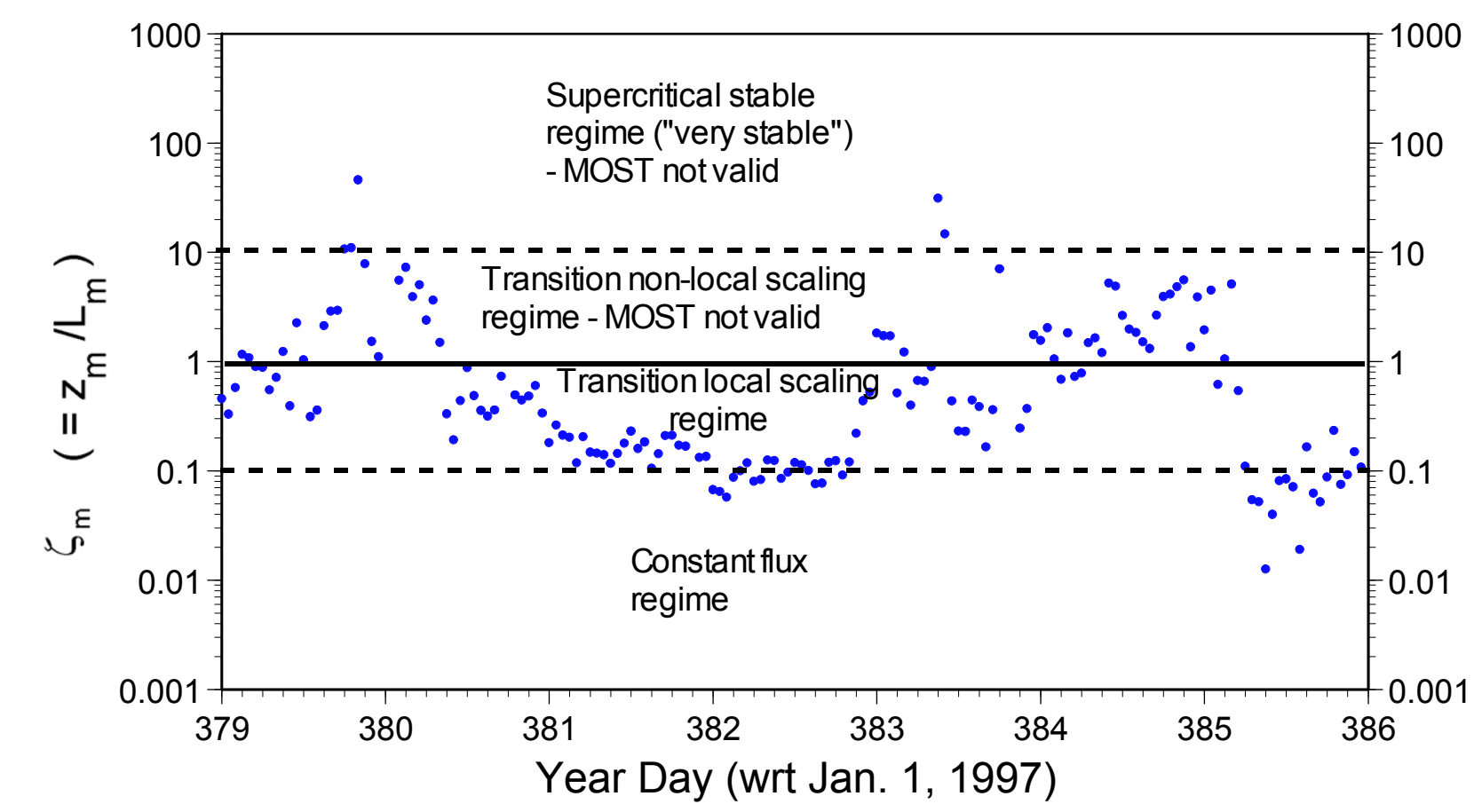


Fig. 5: Time series of the hourly median stability parameter z_m^* ($= z_m/L_m$) where L_m is the median Monin-Obhukov length at height z_m on the 20-m SHEBA tower. Monin-Obhukov Similarity Theory (MOST) is not valid for $z_m^* > O(1.0)$ (See Grachev et al 2002 - paper 7.3 at this conference).

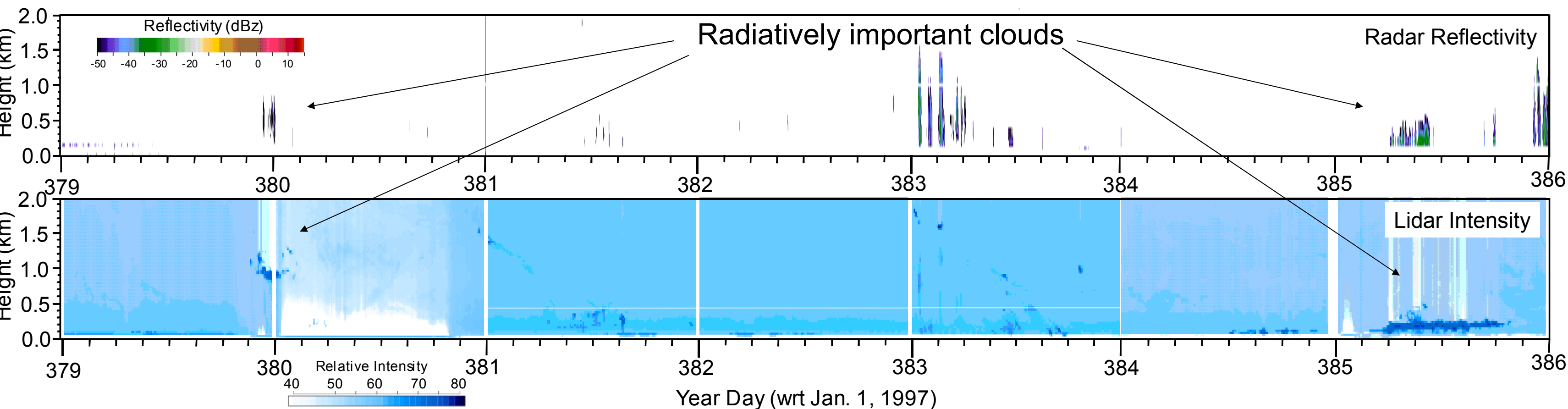


Fig. 3: Cloud radar reflectivity and lidar intensity for Jan. 14-20.

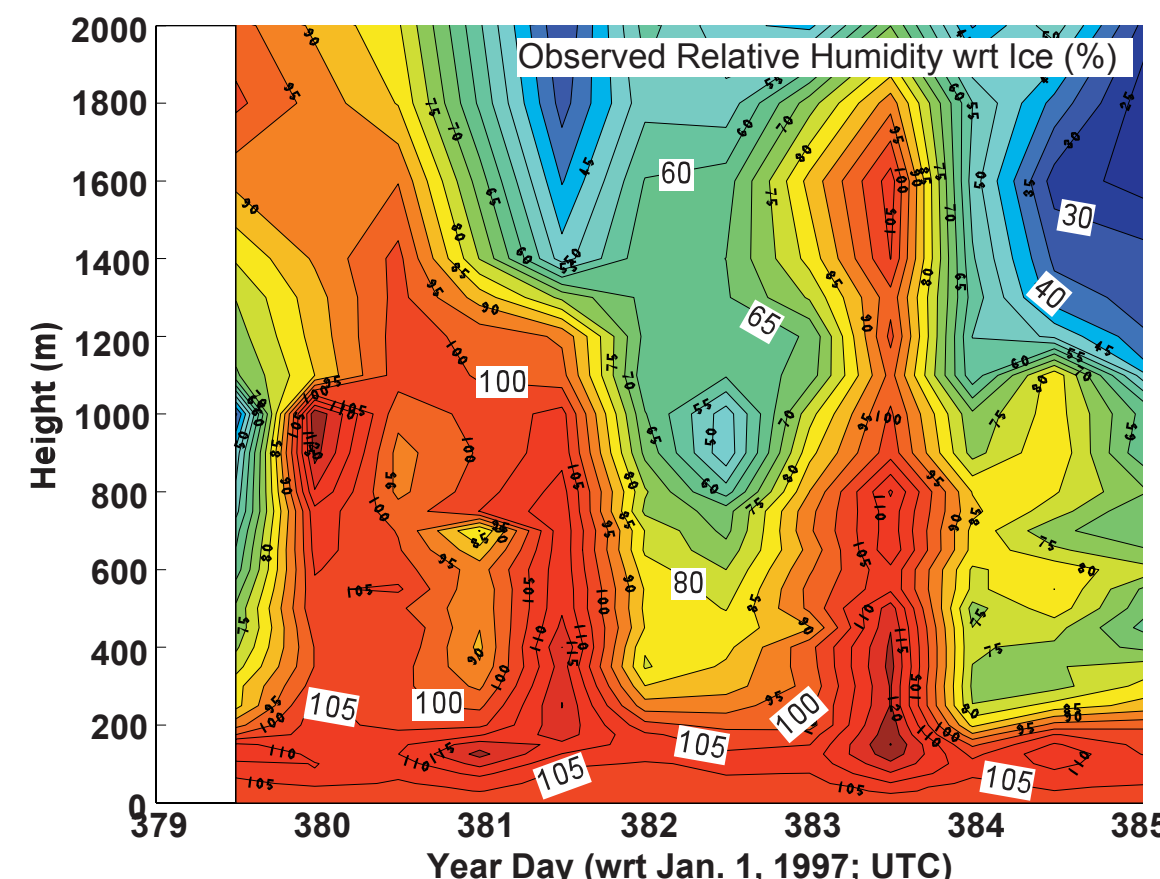
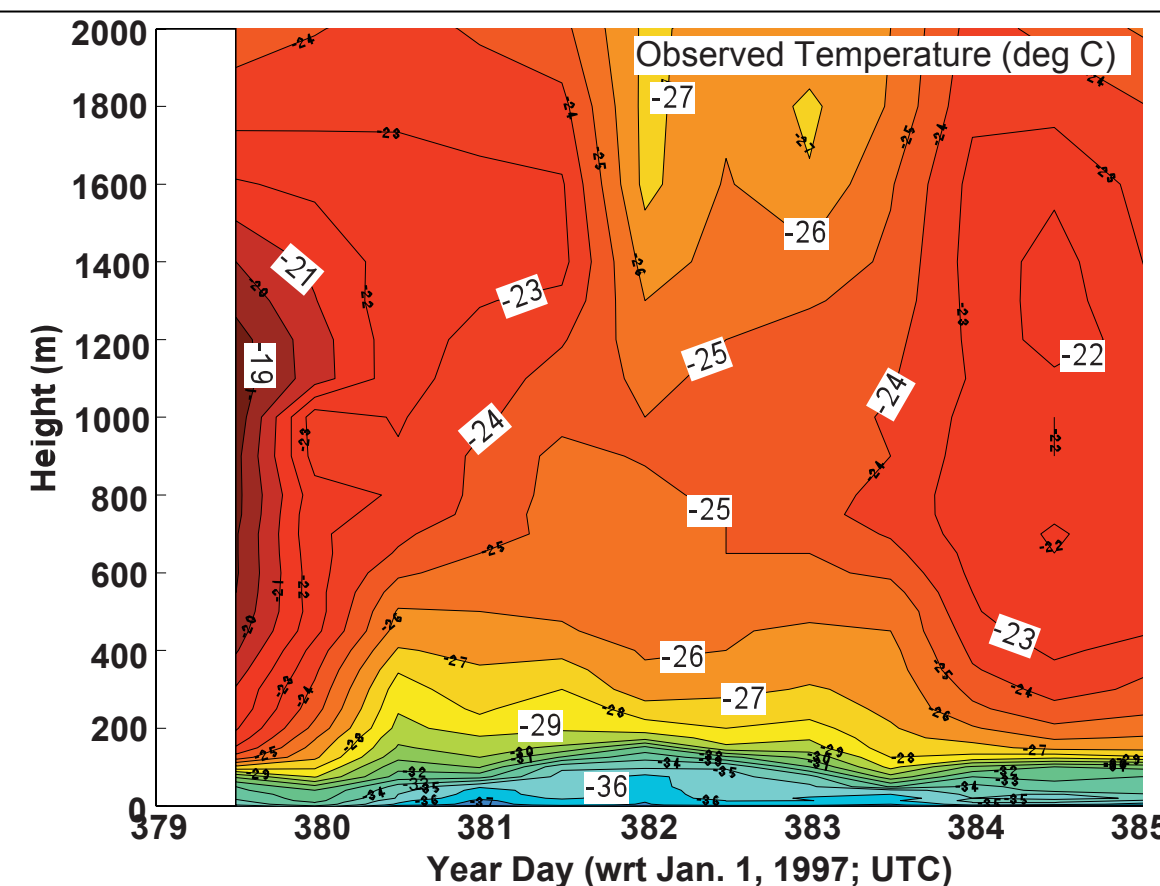


Fig. 2: Time height sections of temperature and relative humidity (wrt ice) in the lowest 2 km of the atmosphere from combined 12-hourly soundings and ASFG tower data for January 14-19, 1998, at the SHEBA site. Supersaturated regions are the darker red shades in b).

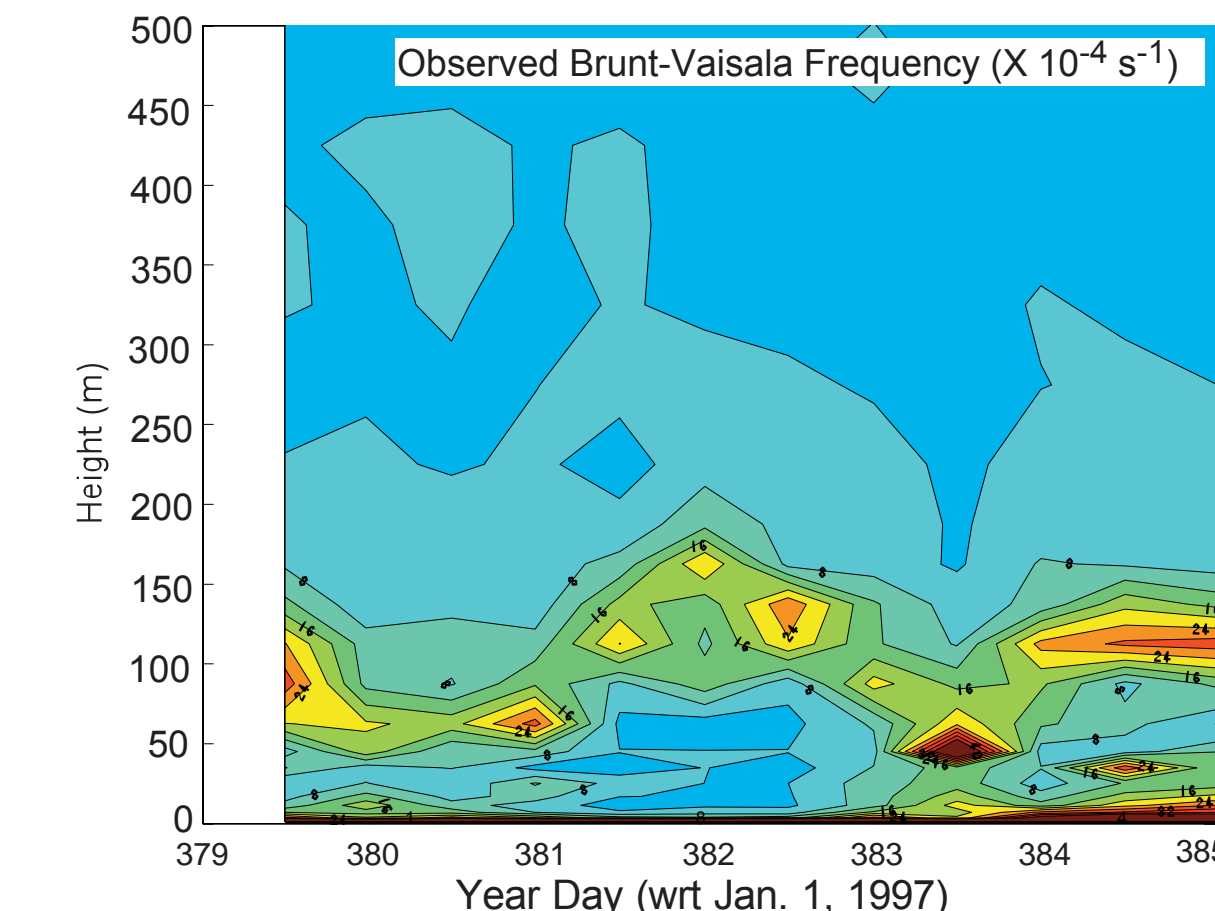


Fig. 4: Observations of the Brunt-Vaisala frequency in the lowest 500 m. The yellow and red shades represent larger values.

MODEL DESCRIPTION

Atmospheric: MM5, 100X100 grid points with $\Delta x=81$ km, 50 vertical levels (40 below 1.6 km – see Fig. 6a), Initial

Conditions: European Center for Medium Range Weather Forecasting (ECMWF) at 00 UTC Jan 15.

PARAMETERIZATIONS: Longwave Radiation: Dudhia (1989) and RRTM (Mlawer 1997). PBL scheme: Blackadar (BK; 1st order; Zhang and Anthes 1982), Burk-Thompson (BT; 2nd order, 1989), Gayno-Seaman (GS; 1.5 order; Shafra et al 2000)

Ice/snow:

Observed ice and snow thickness: 2.2 m and 22 cm, respectively.

Heat diffusion model with variable number of ice and snow layers, using thermal conductivity for snow of $0.3 \text{ Wm}^{-1}\text{K}^{-1}$ and for ice of $2.0 \text{ Wm}^{-1}\text{K}^{-1}$. Tested 1-2 ice layers and 0-5 snow layers (Table 1). With 2 ice layers, the layer thicknesses were 110 cm each. With 3 (5) snow layers, the thickness distribution was 3, 6, & 13 cm (1.5, 2.5, 3, 3 & 13 cm), with thinnest at the top. Sub-ice ocean temperature = -1.8°C .

MODELING RESULTS

Boundary Layer Structure

- 1) Arctic BL thermal structure reasonably simulated, but mesoscale humidity structure above 300 m absent (Fig. 6)
- 2) Planetary BL height of 70-170 m well simulated by 3SNW, including the temporal variation (Fig. 7). Some variations dependent on PBL scheme.

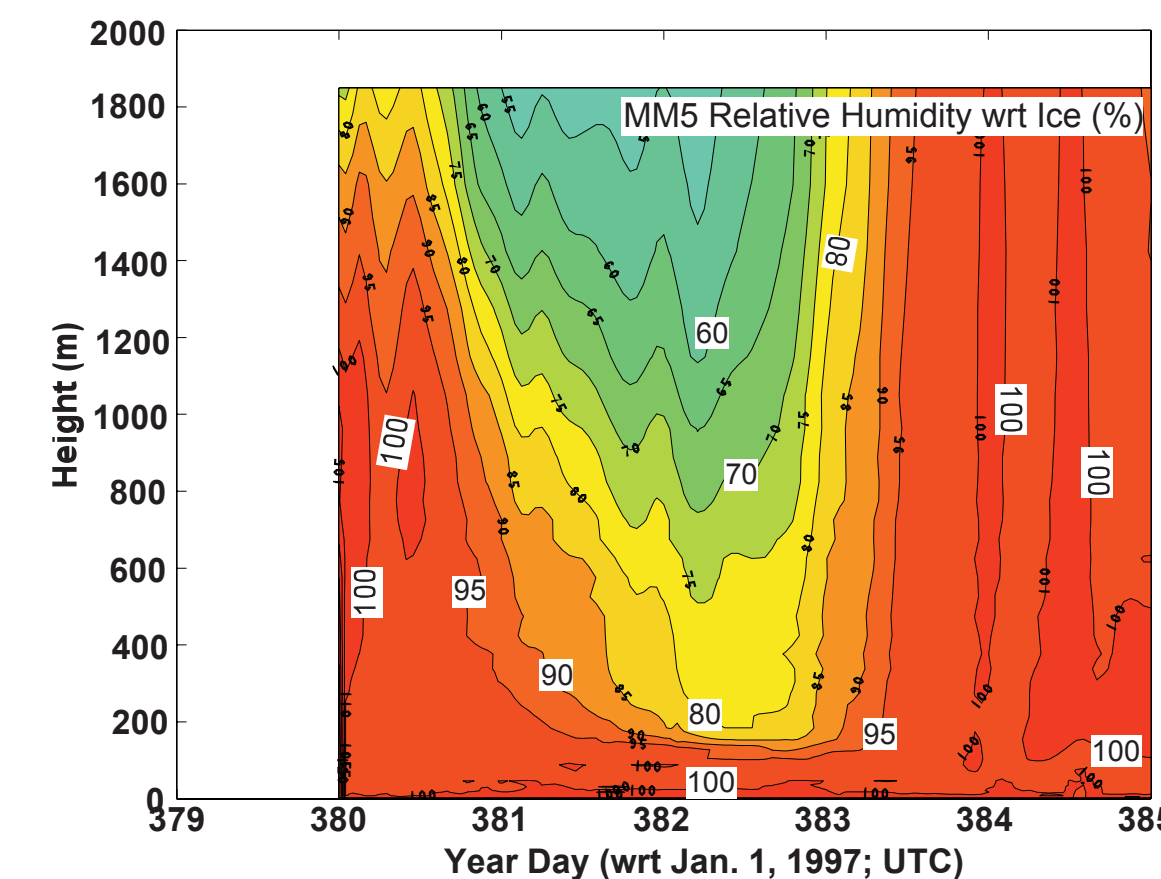
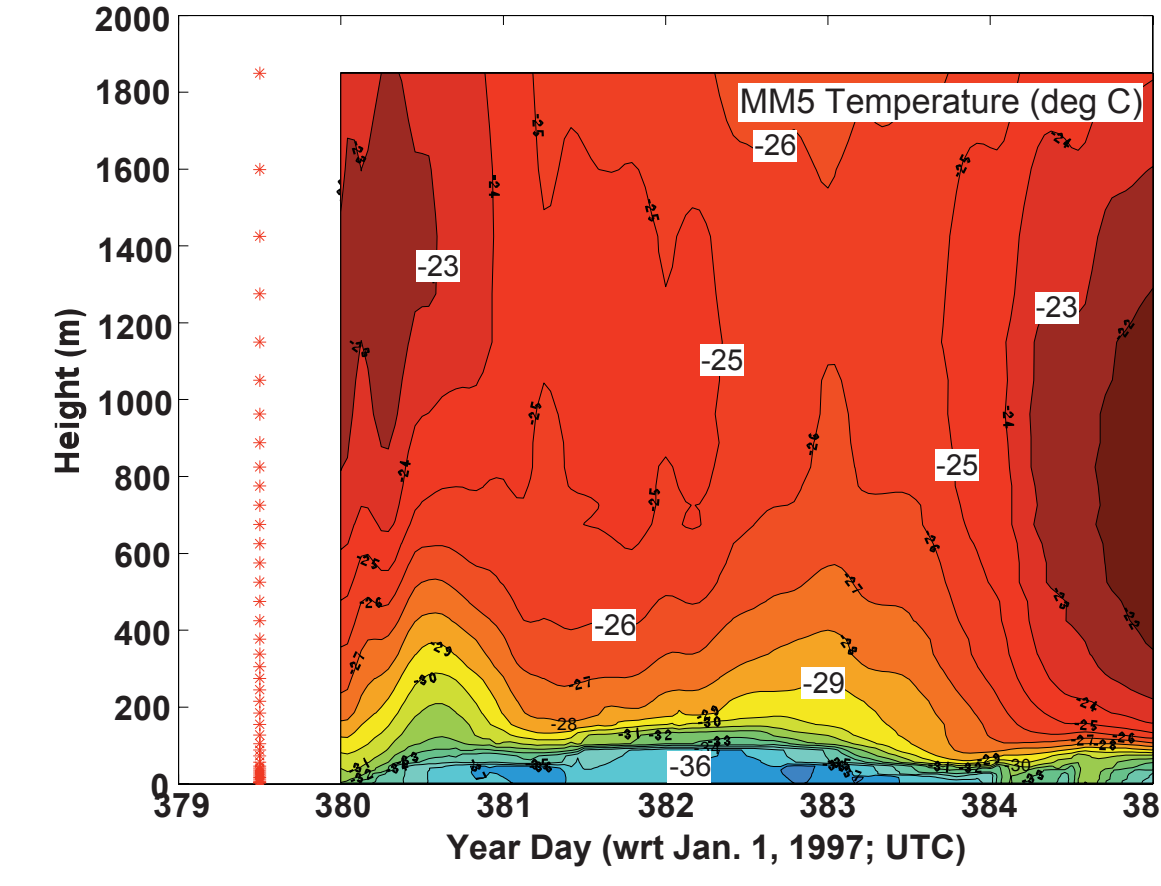


Fig. 6: As in Fig. 2, but for hourly output from the MM5 simulation 3SNW. The stars in a) indicate the model levels.

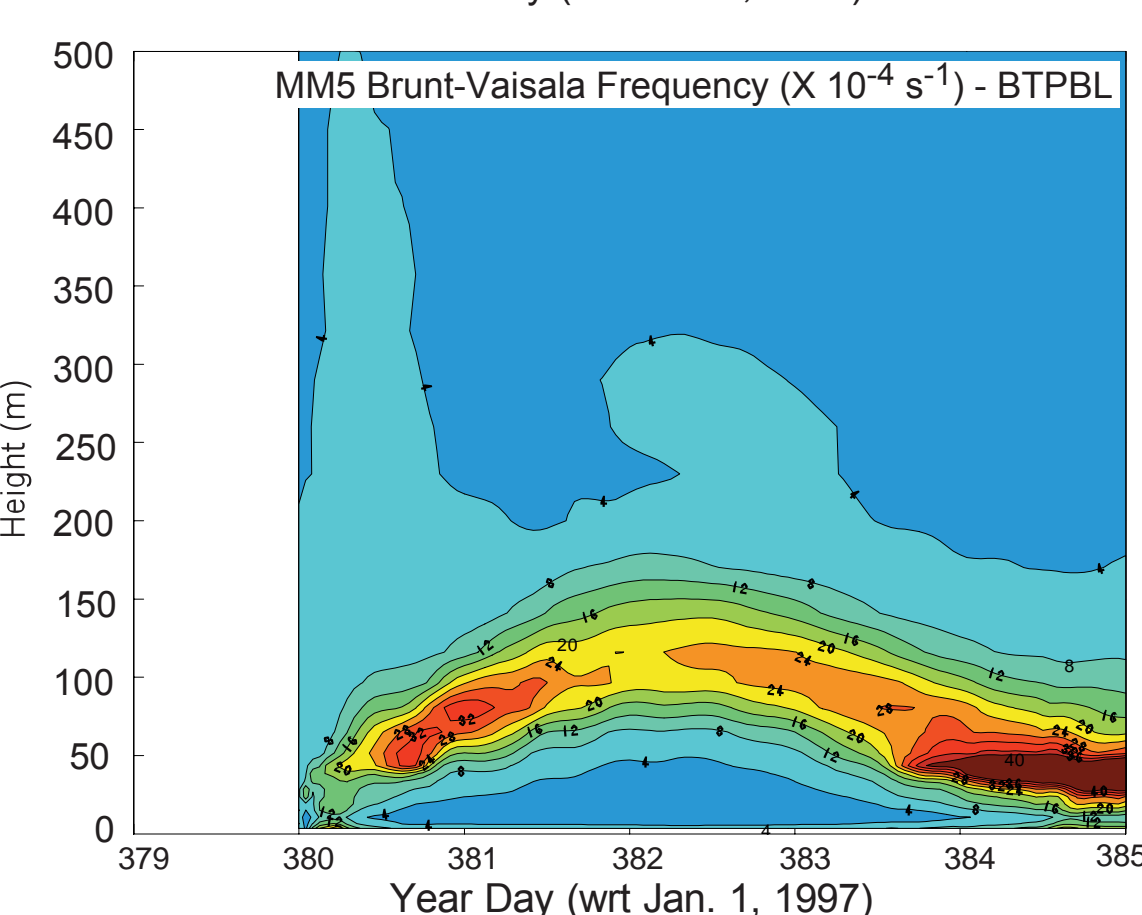
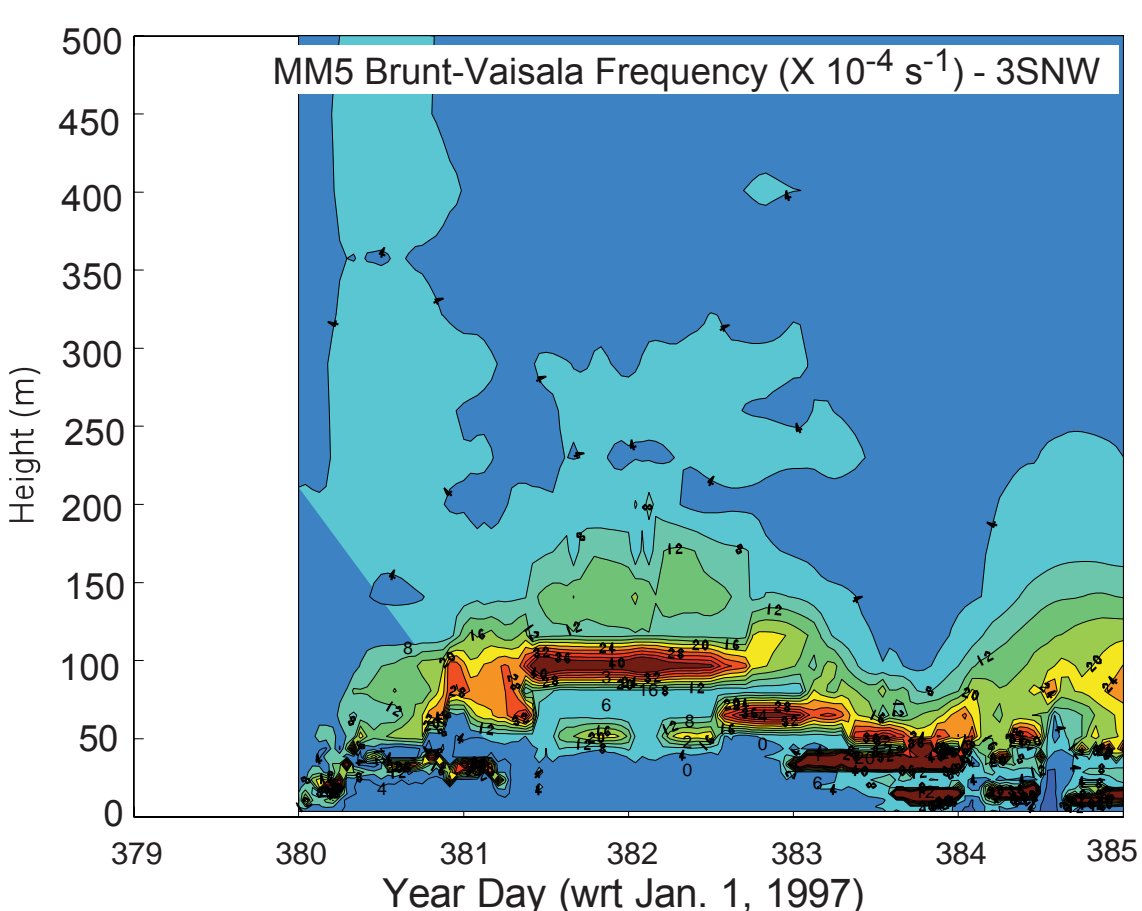


Fig. 7: The Brunt-Vaisala frequency obtained in simulations a) 3SNW and b) BTPBL.

Surface Layer

- 1) Radiation tests show that RRTM longwave scheme superior to Dudhia scheme (Fig. 8a). Incoming longwave radiation (LW_d) still 7 Wm^{-2} low, perhaps because no aerosol effects included. The magnitude of the modeled LW_d impact of clouds is similar to that observed, but occurs at an earlier time in the simulations shown.
- 2) Surface model tests (Fig. 8b) show that a model with at least 2 ice layers and 3 snow layers is necessary to obtain the proper near-surface temperature and the proper temporal response to changes in the radiative forcing. The top snow layer should be thin (< 5 cm). A configuration frequently used in GCMs (e.g., 1SNW) provides inadequate insulation for the atmosphere.
- 3) Varying the boundary layer scheme (Fig. 8c) has some impact on the surface temperature, but not as much as the radiative effect of clouds or the complexity of the surface model.

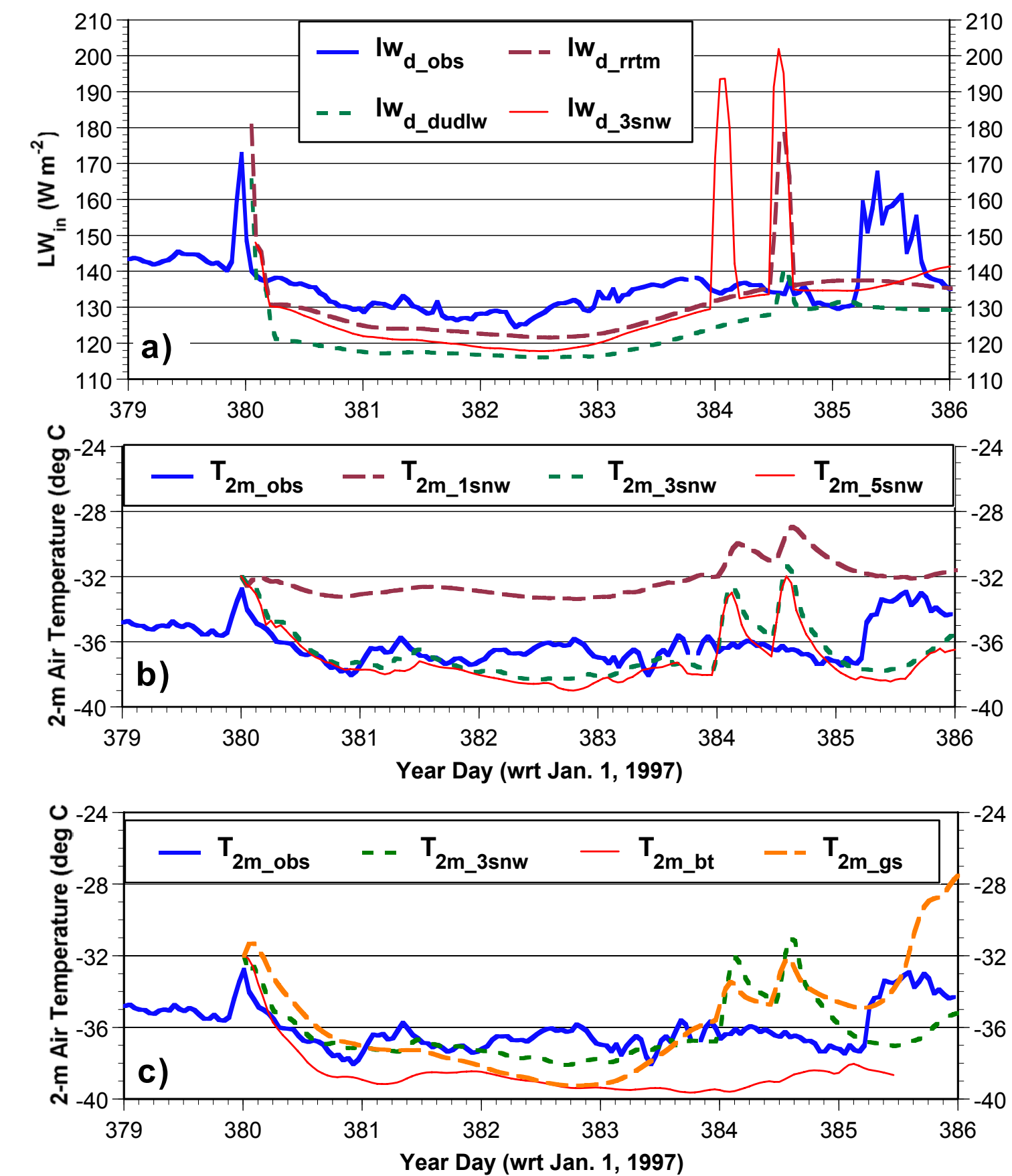


Fig. 8: Time series of a) incoming longwave radiation for the radiation tests (DUDLW, RRTM, 3SNW), b) 2-m air temperature for the snow/ice model tests (1SNW, 3SNW, 5SNW), and c) 2-m air temperature for the PBL tests (3SNW, BTPBL, GSPBL) for January 14-20, 1998. The heavy solid curves are observed values in all panels.

CONCLUSIONS

- 1) The presence or absence of clouds have a major impact on the near-surface Arctic wintertime environment
- 2) A surface model with multiple ice and snow levels is necessary to insulate the Arctic PBL from the warm ocean and provide proper timescales for PBL responses to changes in forcing. Most GCM configurations are inadequate.
- 3) RRTM radiative scheme performs best, but would likely be improved with aerosol concentration profiles since the moisture profile is less dominant because of the small absolute humidity
- 4) sensitivity to PBL schemes observed but much less than the sensitivity to surface model sophistication.
- 5) PBL height and temporal fluctuations in good agreement with observations using the Blackadar PBL scheme
- 6) Momentum and sensible heat fluxes are too large in magnitude, but this is due primarily to excessive large scale pressure gradient and wind in the models rather than significant problems with the flux parameterization schemes. The excessive downward H_s compensates for the reduced LW_d , producing a modeled near-surface temperature that is in good agreement with observations.

Table 1: List of MM5 model experiments.

EXPERIMENT	LW RAD	PBL SCHEME	ICE LAYERS	SNOW LAYERS
DUDLW	DUD	BK	1	0
RRTM	RRTM	BK	1	0
1SNW	RRTM	BK	2	1
3SNW	RRTM	BK	2	3
5SNW	RRTM	BK	2	5
BTPBL	RRTM	BT	2	3
GSPBL	RRTM	GS	2	3

Surface Fluxes

- 1) Momentum and sensible heat flux (H_s) magnitudes are too large in all simulations, though BT PBL scheme generally best (Fig. 9)
- 2) Normalizing by wind speed (Figs. 10 & 11) shows that the reason for the incorrect fluxes is the too strong wind speed resulting from an excessive pressure gradient in the model (Fig. 12). The model drag coefficients are only slightly too large (BT is slightly better than BK), and the sensible heat flux schemes represent the observations adequately. The source of the excessive pressure gradient is uncertain.
- 3) The excessive downward H_s approximately compensates for the reduced LW_d (Fig. 8a), resulting in a good simulation of the near-surface temperature for 3SNW (Figs. 8b & 8c).

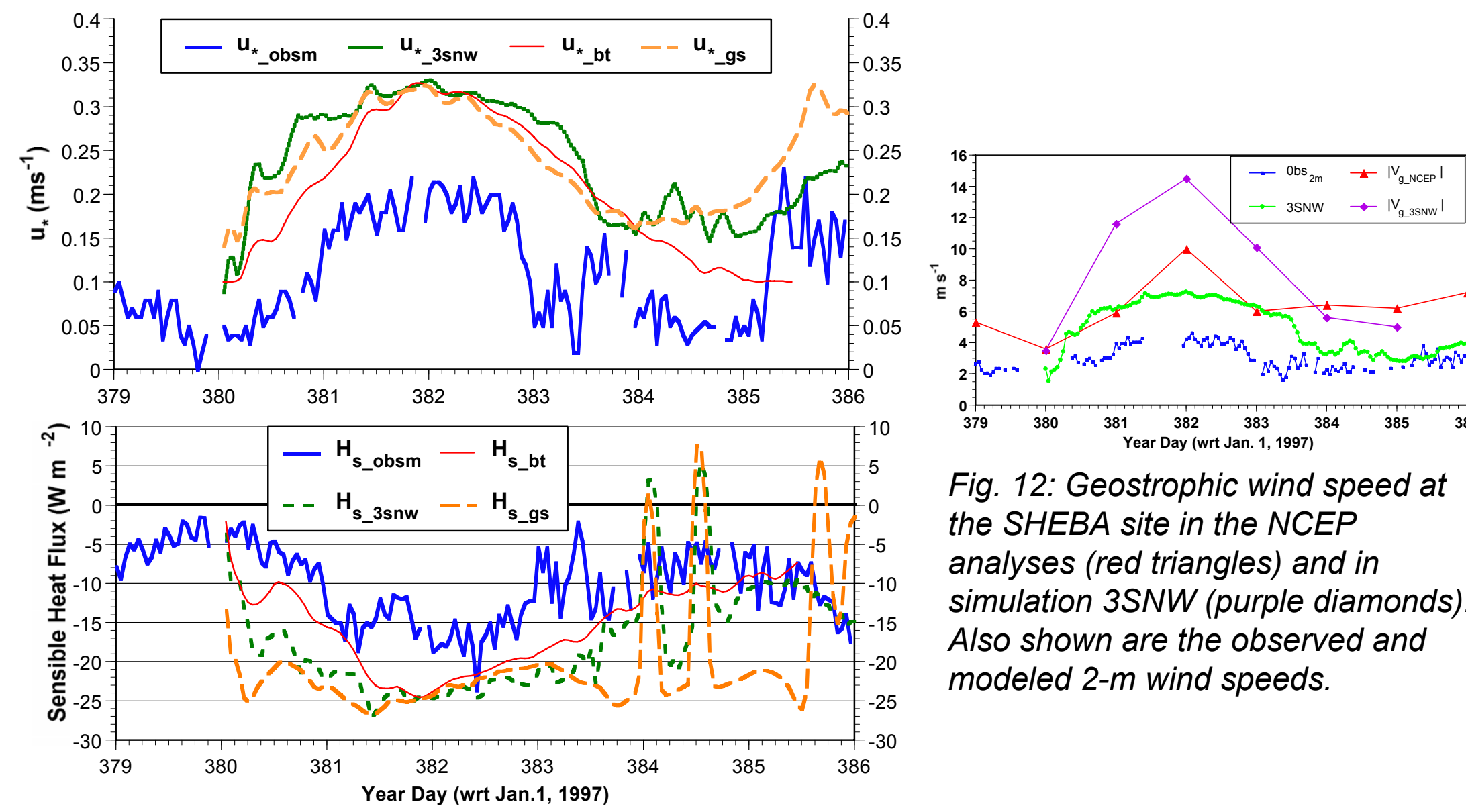


Fig. 9: As in Fig. 8, but of a) u , and b) sensible heat flux (H_s). Shown are median observed values (heavy solid) and those from simulations 3SNW, BTPBL, and GSPBL.

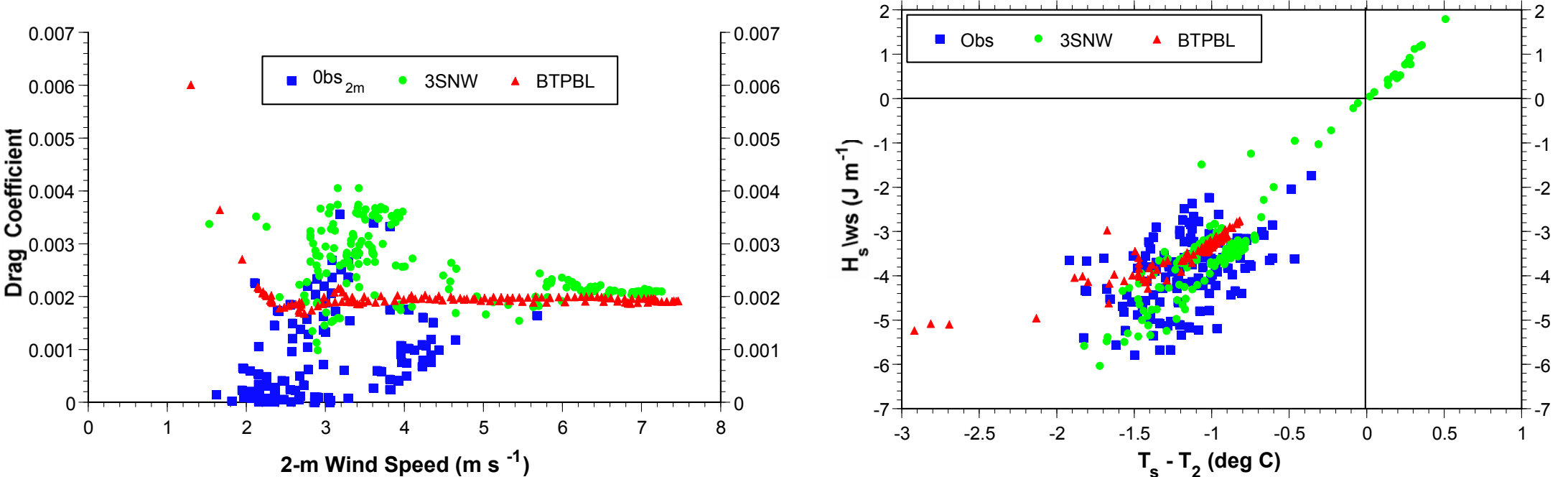


Fig. 10: Drag coefficient as a function of wind speed for the observations and selected simulations.

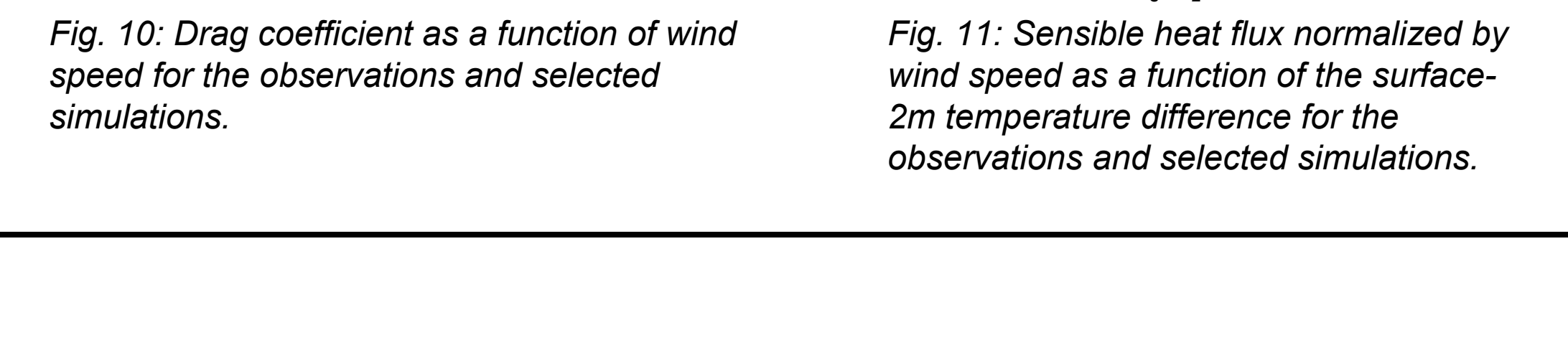


Fig. 11: Sensible heat flux normalized by wind speed as a function of the surface-2m temperature difference for the observations and selected simulations.